EXHIBIT F

UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF MICHIGAN
SOUTHERN DIVISION

IMRA AMERICA, INC., a Michigan corporation,

Plaintiff,

v.

IPG PHOTONICS CORPORATION, a Delaware corporation

Defendant.

Case No. : 2:06-cv-15139

Judge: Hon. Anna Diggs Taylor
Magistrate: Hon. Mona K. Majzoub

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SECOND DECLARATION OF DR. WAYNE H. KNOX, IN SUPPORT OF IMRA AMERICA'S CLAIM CONSTRUCTION

I, Wayne H. Knox, hereby declare as follows:

1. I executed and submitted the declaration in support of IMRA America's Brief on Claim Construction, dated December 8, 2009, which this Rebuttal Declaration is intended to supplement. My December 8, 2009 declaration outlines my qualifications and attaches a copy of my curriculum vitae, including a list of my publications.

2. I have reviewed Defendant IPG Photonics Corporation's Opening Claim Construction Brief and the associated Expert Declaration of Philip H. Bucksbaum, Ph.D., dated on December 8, 2009. I have been asked to provide further opinions on the technical merits of the analysis provided by IPG and Dr. Bucksbaum in connection with certain '630 patent claim terms.

A. <u>Technical Background in IPG's Brief and Dr. Bucksbaum's Declaration</u>

3. In connection with my review of IPG's Opening Claim Construction Brief and Dr. Bucksbaum's December 8, 2009 Declaration, I have reviewed the technical background information provided in both documents. In particular, I have reviewed the information in the "Background" section on pages 2-6 of IPG's Opening Brief, which includes general background information and information about U.S. Patent No. 5,818,630 ("the '630 patent"), as well as the technical background information presented in Dr. Bucksbaum's December 8, 2009 Declaration under the heading "Technology Background" in Paragraphs 10-22 of his declaration.

4. In many ways, I agree with the technical background information in the IPG's Opening Brief and Dr. Bucksbaum's December 8, 2009 Declaration, however I wish to clarify, supplement, and in certain respects correct the technical background information provided in those documents, and have done so in the technology tutorial attached hereto as Appendix A.

B. <u>Technical Field and Person of Ordinary Skill In the Art</u>

5. As discussed above, the '630 patent is directed to the general technological field of fiber lasers, fiber amplifiers, and related components.

6. I understand that an assessment of validity of the claims of the '630 patent is made from the perspective of a person of ordinary skill in the art at the time the patent application was filed. The '630 patent issued from a patent application that was filed on June 25, 1997. Accordingly, 1997 is the relevant time period for assessing the level of ordinary skill in the art for the inventions claimed in the '630 patent.

7. In determining the level of ordinary skill in the art, I understand that the following factors may be considered: (a) the educational level of the inventors; (b) the types of problems encountered in the art; (c) the prior art solutions to those problems; (d) the rapidity with which innovations are made in the relevant technology; (e) the sophistication of the technology; and (f) the educational level of active workers in the field.

8. It is my opinion that a person of ordinary skill in the art at the time of the invention would have an undergraduate degree in optics, optical or electrical engineering, or physics, and also an advanced degree such as an M.S. or Ph.D. degree in optics, optical or electrical engineering, or physics, and several years of hands-on experience in optical system design and construction. Regarding education, the person of ordinary skill in the art would have taken sufficient coursework to become familiar with optical fiber and waveguide theory, and optical fiber and waveguide design. Regarding hands-on experience, the person of ordinary skill in the art would have acquired sufficient hands-on experience to gain a familiarity with optically connecting fibers, the taking of basic measurements on optical fibers, and the building of optical systems, including fiber lasers.

C. "Mode Converter"

9. I understand, as a matter of patent law, that to interpret terms in a patent claim, one must look to the specification as originally filed. I also understand that the claims as originally filed are part of the original disclosure in the patent specification.

10. As originally filed, the invention as set forth in claim 1 broadly included a "mode converter." One of ordinary skill in the art at the time of the invention would have understood the concept of mode conversion, and the types of mode converters used in fiber-optic systems, such as the systems described in the '630 patent. In particular, one of ordinary skill in the art at the time of the invention would have understood, upon reading the original specification and claims of the '630 patent, that the mode converter is a type of converter element used to match the mode of an input beam to the fundamental mode of a multi-mode fiber amplifier. Indeed, the '630 patent specification as originally filed acknowledges that those skilled in the art were familiar with mode converters for other applications. For example, in column 3, lines 34-44, the '630 patent specification mentions the Strasser et al. article "Reflective-mode conversion with UV-induced phase gratings in two-mode fiber," Optical Society of America Conference on Optical Fiber Communication, OFC97, pp. 348-349, (1997), which described using Bragg phase gratings as mode converters. Many other types of mode converters for other applications were known to those skilled in the art at the time of the invention.

11. While I understand that it is common for patent applicants to describe their invention in terms of embodiments and examples for ease of understanding, I also understand that, as a matter of patent law, it is improper to limit the claims to any particular embodiments or examples described in the patent specification, unless a patent applicant explicitly so limits his invention to a specific embodiment or embodiments. I have studied the '630 patent specification and have found no language that explicitly or otherwise limits the term "mode converter" of claim 1 on the invention to an optical imaging system. Moreover, I have studied the file history of the '630 patent, including the related reexamination and its file history, and have found no language that explicitly or otherwise limits the term "mode converter" of Claim 1 on the invention to an optical imaging system.

12. Accordingly, it is my opinion that the claim term "mode converter" is broader than the various examples set forth in the patent specification in this case.

13. Additionally, it is my opinion that the mode converter embodiment recited in Claim 18 (a tapered single-mode fiber) is not an optical imaging system, in the general sense of the term. An optical imaging system is a very general concept in which an optical field at a particular region of space is reproduced at another region of space with certain modified characteristics. The example that I use is that of a projector of the type that we use for presenting PowerPoint talks. The projector creates a very bright representation of the information that we wish to show. For instance, an optical imaging system may amplify or attenuate an image, and the tapered single mode fiber recited in Claim 18 cannot do either of these. Or, an optical imaging system can invert (turn upside-down) an image, and the tapered single-mode fiber cannot do this. Furthermore, an optical imaging system could anamorphically modify an image, by applying different magnifications in the two orthogonal directions (like with new large-screen television sets that can display 4/3 format for ordinary TV or 16/9 wide-screen format), and a tapered single-mode fiber cannot do this. Furthermore, an optical imaging system can provide controlled defocusing, which can introduce a "soft focus" blurring of the image to provide artistic effects, and a tapered single-mode fiber cannot do this. And, an optical imaging system can include spatial filtering, which can provide a large number of combinations of imaging effects from image sharpening to contrast enhancement, etc.; and a tapered single-mode fiber cannot do those. Furthermore, an optical imaging system can provide controllable amounts of lateral image translation, such as when we align an optical projector to a projection screen to fit best. A tapered single-mode fiber cannot provide this once it has been fused to the multi-mode fiber, since the lateral alignment is fixed forever once it is fused. Furthermore, optical imaging systems can operate over a wide range of numerical apertures, which can be thought of as the "f-number" settings on a camera. The "f-number" of a camera lens is the focal length divided by

the aperture size. This determines the amount of light that an imaging lens can capture and image. Imaging lenses on typical cameras run from maximum "f-numbers" of 22, which collects a small amount of light with a small aperture for daylight photography, to f/1.5, which is good for low light levels with a large aperture to collect light. In contrast, a tapered single-mode fiber has a fixed numerical aperture, since there is a maximum angle at which light can be captured at the input. Therefore, a tapered single-mode fiber cannot image over a wide range of "f-numbers" like a camera lens. An imaging system can also include optical filters for controlling the spectral content (color) of the light that is imaged. A tapered single-mode fiber does not have this characteristic.

14. Additionally, it is my opinion that the mode converter embodiment recited in Claim 19 (a combination of a bulk-optics imaging system and a tapered fiber) is not an optical imaging system. By a simple logical extension of the factual reasoning in Paragraph 13, we can see that if we take any kind of imaging system that can perform the kind of general functions described, then if we form the combination of the imaging system together with the tapered single-mode fiber, then the resulting optical system is not an imaging system that can perform a wide range of functions, since the combination is still limited specifically by the capabilities of the tapered fiber. For instance, if the magnification of the bulk-optics imaging system were increased to attempt to more precisely match the fundamental mode of a multi-mode fiber, the tapered fiber would not allow the changed input mode pattern to be magnified. If the optical imaging system part were adjusted for lateral image translation, the tapered fiber would not pass the new alignment along to the output, rather a different group of higher order modes would be excited and this would not achieve the desired enhanced coupling to the fundamental mode of the multi-mode fiber. The f-number of the imaging part would not be limited, however the combination of an imaging system and a tapered fiber would specifically limit the f-number. If

the imaging part were adjusted to provide an anamorphic image, the tapered fiber would not be able to maintain the anamorphic ratio.

15. In my opinion, IPG in its Opening Claim Construction Brief, and Dr. Bucksbaum in his December 8, 2009 Declaration, mischaracterize what the '630 patent states or teaches. In my opinion, IPG and Dr. Bucksbaum are wrong to misstate that the '630 patent provides a "definition" for a mode converter that is limited to an optical imaging system. Instead, IPG and Dr. Bucksbaum attempt to improperly support their position that the '630 patent defines the term "mode converter" as an optical imaging system by citing a portion of the specification that says "[t]he mode-converter 50 ***can consist*** of any type of optical imaging system capable of matching the mode of the MM amplifier 52." (Col. 10, lines 26-28, emphasis added.) In other words, far from specifically limiting the "mode converter" to only an optical imaging system, the cited portion of the specification is merely an example.

16. Moreover, at Paragraphs 28-30 of Dr. Bucksbaum's December 8, 2009 Declaration, he provides his analysis of an Amendment submitted by IMRA in connection with the U.S. Patent Office's reexamination of the '630 patent. Dr. Bucksbaum focuses in particular on the figure on page 16 of the amendment submitted on June 1, 2009 in that reexamination, and concludes his analysis by stating, "[t]o achieve the focusing depicted in this figure, the claimed mode converter must be an optical imaging system." I disagree with Dr. Bucksbaum's conclusion that, based on this information, the mode converter "must be an optical imaging system." In particular, I have studied the June 1, 2009 amendment and have found no language that explicitly or otherwise limits the term "mode converter" of claim 1 to an optical imaging system of the type shown in that figure or otherwise referenced in the reexamination papers. To the contrary, the figure on page 16 of the June 1 amendment is referred to as "***[a]n illustrative example*** of matching the fundamental fiber with an input beam." (Emphasis added.)

17. In my opinion, a person of ordinary skill in the art would not rely on the illustrative example shown in the figure on page 16 of the June 1, 2009 amendment to limit the claim term "mode converter," such that it would exclude examples of mode converters that are not optical imaging systems, but which were either commonly known or explicitly recited in the '630 specification, such as tapered fibers or other similar elements.

D. "Converting the Mode of the Input Beam to Match a Fundamental Mode of the Multi-Mode Fiber Amplifier"

18. As I pointed out in my December 8, 2009 Declaration in support of IMRA' Brief on Claim Construction, I disagree that a person of ordinary skill in the art at the time the '630 patent was filed would add the unnecessary phrase "to cause it," as IPG suggests in its Claim Construction Brief. First, it implies a causal relationship that does not necessarily exist. That is, "converting the mode of the input beam" does not necessarily or exclusively cause the beam "to match a fundamental mode of the multi-mode fiber amplifier." In addition to the requirement of mode-matching, the mode converter needs to be precisely aligned in order the cause the beam's energy to be transferred substantially to the fundamental mode alone. For instance, I could convert the mode of the input beam to a shape that would in principle match the fundamental mode of a multi-mode fiber amplifier, but then I could deliberately misalign the mode converter, which would cause it to not couple a substantial fraction of the power to the fundamental mode of the multi-mode fiber. Therefore, the additional causal language IPG suggests should be added is unnecessary.

19. At Paragraph 15 of Dr. Bucksbaum's December 8, 2009 Declaration, he provides a discussion of multi-mode fibers. I strongly dispute Dr. Bucksbaum's statement that "an MM fiber always supports a mode with the same general shape as the mode in an SM fiber." There can be significant differences in the shapes of the fundamental modes in different MM fibers, depending upon the details of the materials and structural design properties of the fiber (core

doping distribution, index gradients, core diameter, index of refraction profile, use of depressed cladding layers, etc.) Likewise, there can be differences in the shapes of the modes in different SM fibers, depending upon those same types of details (core doping, index gradients, core diameter, cladding details, index of refraction profile, etc.) The differences can be quite significant in the wings (outer diameter portions) of the fiber modes, which can carry a significant amount of total power. Accordingly, it is simply not true that all fundamental modes in MM fibers and all modes in SM fibers have equivalent shapes, and in the present case with very high power fiber lasers at issue, small fractions of large optical powers can have important effects and they cannot be neglected. Dr. Bucksbaum's statement that "an MM fiber always supports a mode with the same general shape as the mode in an SM fiber…" is careless and inapplicable to the present case involving extremely high power fiber lasers.

E. <u>"Mode-Converted Input Beam"</u>

20. On page 18 of IPG's brief, it suggests that I agree with IPG's proposed interpretation of the claim term "mode-converted input beam." IPG also quotes from my expert report on infringement, suggesting that my quotes support IPG's proposed definition for this claim term. The quotes cited by IPG are not statements I made while interpreting this (or any other) claim term. Rather, the quotes are statements I made discussing specific embodiments disclosed in the '630 patent specification, and IPG is using the quotes out of context. This is improper and wrong. The quotes support interpreting the claim term "mode-converted input beam" to have its plain and ordinary meaning as understood by a person of ordinary skill in the art.

F. <u>"An Amplified Beam Substantially in the Fundamental Mode"</u>

21. Figures 3 and 4 of the '630 patent are illustrative autocorrelation plots that show information on the time sequence of a propagating series of pulses. To a person of ordinary skill in the art, these types of plots may be used to accurately quantify timing. In my opinion, Dr.

Bucksbaum improperly uses these figures for a purpose for which they were not intended. Specifically, Dr. Bucksbaum attempts to use these figures to obtain quantitative information based on incomplete information, and therefore his analysis in invalid.

22. An autocorrelation plot would ***not*** be used by a person of ordinary skill in the art to accurately quantify the energy content in different modes of light, unless it had been specifically calibrated to do so. Indeed, it was well known to a person of skill in the art at the time of the '630 patent invention that autocorrelators do not give unique measurements of pulse shapes. Rather, they give an averaged measure of the intensity autocorrelation with all time direction and all phase information discarded. Furthermore, they give a spectrally filtered measurement of the light field, depending on the phase matching conditions that were used, which can lead to significant distortions in measurements. Unless specifically calibrated using a laborious procedure, they do not give actual reliable measurements of pulse energy. This has led to the development of other, more accurate methods to measure pulse shapes, such as "FROG," representing Frequency-Resolved Optical Gating, or "SPIDER," representing Spectral Phase Interferometry for Direct Electric-field Reconstruction. The autocorrelation measurements shown in Figure 3 and 4 were not taken using these sophisticated techniques.

23. At Paragraph 27 of his December 8, 2009 Declaration, Dr. Bucksbaum states that he conducted a "first order analysis" of the data in Figure 4 of the '630 patent, resulting in a calculation that all of the higher order modes together had about 20% to 25% of the total pulse energy, leaving about 75% to 80% of the energy in the fundamental mode. I do not believe that Dr. Bucksbaum's analysis is technically sound, and I also do not believe he has any basis for believing that his numbers are accurate. Figure 4 together with the information in patent '630 provides insufficient information to allow for a reliable calculation of pulse energies, since the autocorrelation experiment was not calibrated to take into account the mode overlap cross-products. In other words, the autocorrelation measurement takes the light intensity distribution in

time *and in space* and forms a product through the use of a second-order nonlinearity such as second harmonic generation in a nonlinear crystal. Each higher order mode will overlap in space and in time in a way that depends on many factors that are unknown in the experiment. The extent of that mode overlap is unknown since all the experimental details were not provided. The overlapping of the higher order modes with the fundamental mode can provide numerical factors with a maximum value of unity (1.00) or they could be much smaller. Therefore, the autocorrelation of a higher order fiber mode with a fundamental mode is not a reliable method of measuring the amount of power contained in the higher order mode. In fact, the mode overlaps for higher order modes are even more complicated, and therefore the presence of higher order peaks in the autocorrelation is more difficult to interpret, other than the fact that the timings of the peaks are identified. Dr. Bucksbaum necessarily had to make assumptions to make his calculations, and he has no way of knowing the accuracy of those assumptions. Dr. Bucksbaum even alludes to this problem at Paragraph 25 of his December 8, 2009 Declaration, where he states that peak height may be used to approximate relative strength "under some conditions." The situation reflected in Figure 4 does not represent conditions that are suitable for making simple approximations of peak strengths.

24. There are several reasons why Figure 4 is inadequate for purposes of reliably calculating the amount of energy in higher order modes:

- As a simple example, we consider a light signal that consists of two pulses separated in time. In a first case, the first pulse has 100 times as much power as the second pulse: An autocorrelation with three peaks with one strong central peak would be produced, and two small peaks, one on each side separated by the time difference between the pulses. In a second example, the first pulse has 100 times less power than the second pulse. ***In this second case, the autocorrelation would be exactly the same.*** This happens because the autocorrelation cannot

distinguish the time direction of a signal. This situation could correspond to a case where the LP_{01} mode, being the fundamental mode, has the shortest time delay and the LP_{11} would have a larger time delay. Therefore, it would be possible to have only 1% of the power in the fundamental mode and 99% of the power in the first higher order mode, and still obtain an identical autocorrelation. I note that the vertical scales in Figure 3 and Figure 4 are labeled "a.u." which is typically used to mean "**a**rbitrary **u**nits." This indicates that these were uncalibrated measurements and not meant to convey specific pulse powers or energies. Furthermore, following this logic, an autocorrelation plot with the appearance of Figure 4, for example, could even result from a beam that has ***no power whatsoever in the fundamental mode***.

- Dr. Bucksbaum provides no details that would allow me to understand what he did as part of his "first order analysis." He would have had to assume that the higher order modes had the same efficiency in generating signals in the autocorrelation as the fundamental mode, and as we said, there is not enough information to support this. For example, the divergence of the higher order modes is always higher than the divergence of the fundamental mode, which can reduce the signals generated in the autocorrelator.

25. For the above reasons, I believe that Bucksbaum did not accurately or reliably calculate from Figure 4 the fraction of power propagating in the fundamental mode (or higher order modes) of the beam.

26. On page 19 of IPG's brief, IPG uses Figure 3 of the patent to quantify a definition for "substantially in the fundamental mode." Specifically, IPG equates that claim term to an amplified beam that has "at least 99% of its energy content in the fundamental mode." I disagree with IPG's analysis for three reasons. First, for the many reasons discussed above, a person of

ordinary skill in the art would not try to use Figure 3 to make a reliable quantitative measurement of energy in the fundamental mode. IPG quotes a portion of my infringement report where I refer to the power in the first higher order mode to be "a very small amount (in this example, about 1%)." IPG is reading far too much into my statement. I intentionally indicated that the power is "***about*** 1%," meaning that it could be less (such as 0.5% or 0.25%) or it could be more (such as 2% or 3%). Each of these would qualify as "a very small amount." IPG also ignores the presence of power in modes above the first higher order mode. Thus it is improper to conclude from my statement (as IPG has done) that Figure 3 shows an amplified beam with "at least 99%" of its power in the fundamental mode. In fact, the proper way to interpret Figure 3 is that it was the result of a *best effort* to adjust the alignment and properties of the mode converter so as to minimize the height of the secondary autocorrelation peaks. Patent '630 says exactly this in col. 10 line 8: "…under optimum mode-matching conditions, any secondary peaks are suppressed to better than 1%..."; and Figure 4 represents non-optimum mode-matching; again quoting from patent '630 col. 10 at line 5: "…Under non-optimum mode-match, the autocorrelation displays several peaks…" Therefore, it is sufficient for a person of ordinary skill in the art to look at Figure 3 and Figure 4 and understand that Figure 3 represents the achievement of optimum mode matching, and Figure 4 represents a typical result that can be obtained when higher order modes are excited. It is not necessary to quantitatively interpret the peak heights into actual energy or power values in order to understand the patent.

27. Secondly, a person of ordinary skill in the art would not consider Figures 3 or 4 of the patent to be a definition of "substantially in the fundamental mode." Figures 3 and 4 are clearly illustrative. A person of ordinary skill in the art would not expect all fibers to behave in the same way, and different fibers would behave differently than the exemplary fiber used to create Figure 3. Indeed, even my statement quoted by IPG on page 19 of its brief expressly

states, "in this example." Thus, while Figure 3 is ***an example*** of an amplified beam substantially in the fundamental mode, it is improper to consider that figure as ***the definition*** of such a beam.

28. Thirdly, IPG's purported "definition" limiting the claim term "substantially in the fundamental mode" to amplified beams with at least 99% of its power in the fundamental mode is inconsistent with the '630 patent specification. Specifically, Figure 2 of the patent discloses exemplary test results for an optical amplification system used to practice the invention. A person of ordinary skill in the art reading the '630 patent would interpret these test results to show that much less than 99% of the power the power in the beam leaving the amplifier was propagating in the fundamental mode. While Figure 2 should not be used as the definition of a beam that is substantially in the fundamental mode (just as Figures 3 and 4 should not be), it demonstrates the unreasonableness of IPG's proposed definition.

I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct and that I executed this declaration on December 23, 2009, at Rochester, New York.

Wayne H. Knox

APPENDIX A

I. GENERAL BACKGROUND OF THE TECHNOLOGY

A. Lasers and their Applications

1. Stimulated Emission

1. One of the critical events that led to the invention of the laser was when Albert Einstein introduced the concept of stimulated emission of light in the early 1900s. Atoms have their lowest energy level (i.e., the ground state), in which they normally exist, and higher, excited energy levels, in which they do not normally exist. In the process of stimulated emission of light, an atom or a group of atoms is placed into an excited state by some external means such as light or other means of energy transfer. The atoms, once placed into their excited states, can radiate light spontaneously. This is called spontaneous emission of light and differs from stimulated emission in important ways that are described below. Light emitting diodes (LEDs) work by spontaneous emission, for example.

2. But the light from LEDs, while appearing bright to the eye, is generally not bright enough to carry out industrial processing operations like cutting steel plates, welding, etc. This is because the spontaneous light emission from an LED has limited brightness. LED light travels in different directions, at different wavelengths, and with different polarizations, resulting in low brightness. To make a higher intensity light source, it is helpful to make all of the emitted light particles, known as "photons," substantially identical so that they travel in the same direction and have the same wavelength and phase (i.e., the peaks and troughs of the light waves are aligned). This is made possible by use of the stimulated emission process first pointed out by Dr. Einstein, together with a special optical cavity configuration.

3. The stimulated emission process may be used to amplify light to a higher intensity in a manner similar to the way that an audio amplifier may be used to amplify sound that is captured with a microphone. The steps in the process of stimulated emission will now be

discussed in connection with Figure 1, below. Atoms can exist in several different discrete energy levels commonly known as "states." The energy states for a given atom are discrete in that the different states are spaced apart by energy gaps. Step 1 shows an atom in its lowest energy state, known as its "ground" state. In step 2, the atom absorbs energy in the form of light (i.e., absorbs a photon). When an atom absorbs light, this process is commonly referred to as "exciting" the atom, or placing the atom into an "excited state." Any energy state of the atom that has an energy higher than that of the lowest energy state may be referred to as an excited state. The excited state is represented pictorially in Figure 1 by the triangles around the atom. In step 3, the atom interacts with an incoming stimulating photon whose wavelength (i.e., color) is resonant, or aligned, with the energy of the state of the atom. This incoming stimulating photon is shown pictorially by a red lightning bolt in Figure 1. This interaction causes a second identical, stimulated photon to be emitted by the atom, as represented pictorially by the second, identical red lightning bolt. Notably, this second stimulat***ed*** photon travels in the same direction as the stimulat***ing*** photon, and it has the same wavelength and the same phase as the stimulating photon. Once the atom emits the stimulated photon, it returns to its ground state, as shown in step 4. This process can be repeated many times to create a very large number of identical photons, resulting in the stimulated amplification of light.

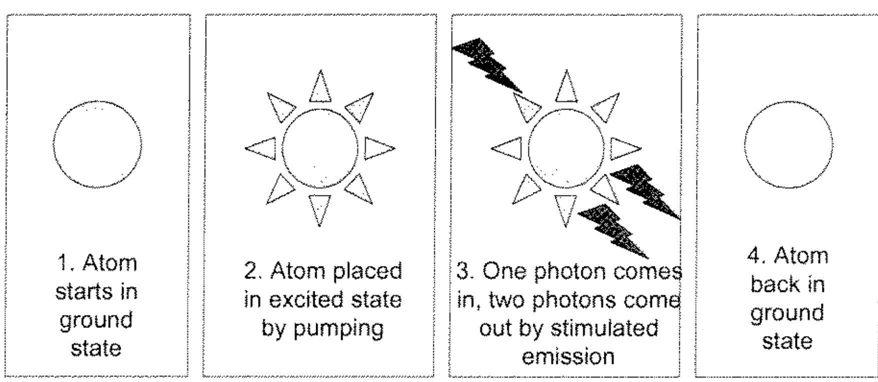

FIGURE 1.

Steps in absorption and stimulated emission.

4. An important aspect of this process is that it has provided a new photon that was added to the incoming one, thus increasing the intensity of the light beam. Therefore, we now have a light amplifier that we can use to increase the intensity of light signals, as long as we use light of the correct wavelength, as well as the correct materials for the amplifier. Ultimately, by adding more and more identical photons, we can build a laser system that is so powerful it can drill through several inches of steel or rock.

2. Laser Cavities

5. We are all familiar with the concept of audio feedback from our experiences at concerts and other events at which live sound systems are used. Audio amplifiers are used to increase the intensity of sound signals that are generated by microphones, guitars, etc. Yet, we also know that if a microphone is placed too close to the speakers, the sound from the speakers may be sensed by the microphone, causing it to be amplified again by the amplifier, the output of which is sensed by the microphone, etc. The result is a cycle that causes a loud tone which can only be stopped by breaking the cycle, for example, by turning the volume of the amplifier down or by moving the microphone farther away from the amplifier. This is a feedback process, and it can be applied to light as well.

6. As explained above, a group of atoms that have been placed in their excited states will emit photons spontaneously in many directions, but the light will be hard to capture and use effectively since it travels in different directions with different wavelengths and phases. However, as shown below in Figure 2, if a pair of mirrors is placed around the group of atoms, a small number of spontaneously emitted photons that happen to travel in just the right direction will bounce back and forth between the mirrors and thus will pass through the space, or "cavity," between the mirrors multiple times. With each pass these photons will stimulate the emission of additional identical photons, which then each stimulate additional identical photons, increasing the light intensity many times over by stimulated emission. The photons emitted by the atoms

within the cavity will be nearly identical, and there will be lots of them. This is commonly known as a "laser cavity." The direction of the photons may be controlled by controlling the mirror properties. Figure 2 compares the light emission process with, and without, the presence of mirrors to create a reflecting cavity.

7. Many kinds of different lasers have been created since the first demonstration of the ruby laser by Theodore Maiman. Solid state lasers, such as ruby lasers, consist of certain kinds of atoms such as Chromium, Ytterbium or Neodymium, for instance, doped into a crystal host such as ruby, sapphire, or glass. Gas lasers, such as the carbon dioxide laser, were developed in the early 1960s at Bell Labs. They have been developed into industrial powerhouses, capable of large-scale manufacturing. Even larger lasers have been developed, such as gas-dynamic lasers that have reached megawatt power levels for short times.

8. Ordinary materials can be divided into (1) insulators, (2) conductors, and (3) semiconductors. "Insulator" are materials that do not conduct electricity. "Conductors," such as metals, are materials that do conduct electricity, and "Semiconductors" are materials that may or may not conduct electricity depending on how they are connected. Semiconductors can be made into lasers. Also developed at Bell Labs in the 1970s, semiconductor lasers today are reliable and compact light sources that can even operate on battery power. These semiconductor lasers can be smaller than a grain of salt, and they are used in CD players and laser pointers.

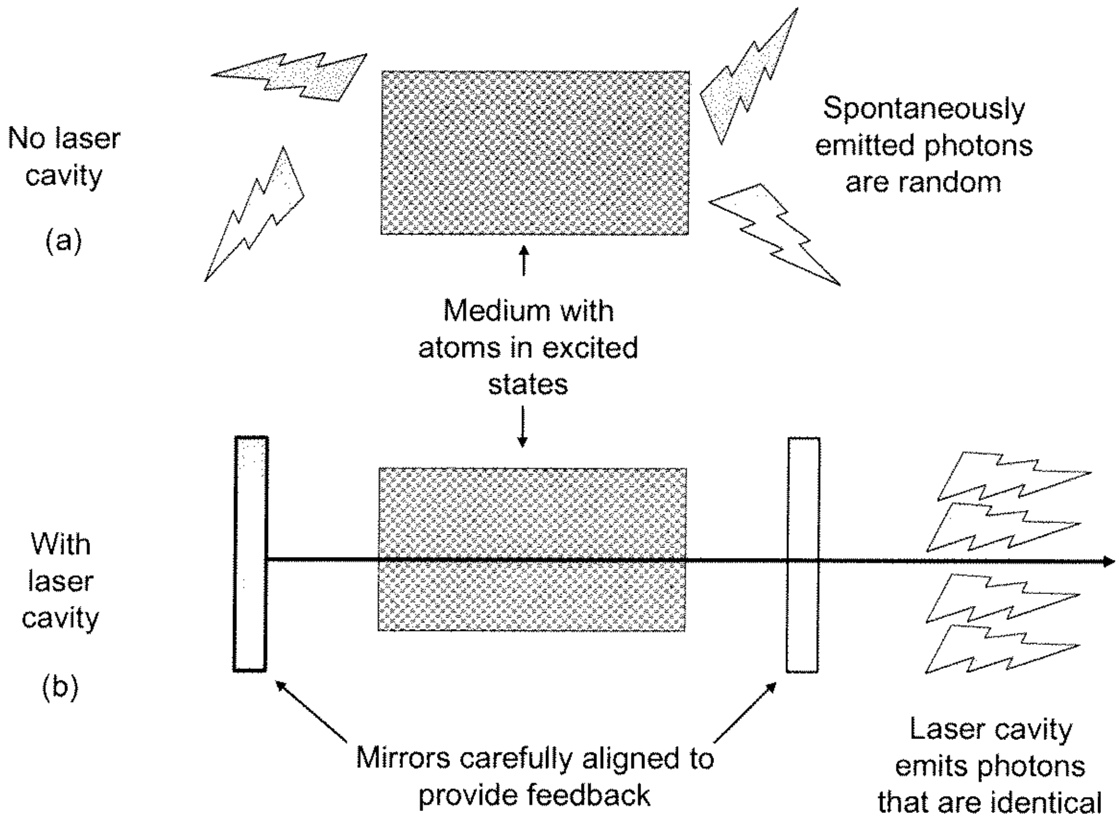

FIGURE 2.

When there is no reflecting cavity (a), photons are emitted spontaneously in all directions. When a pair of mirrors confines the stimulated photons (b), the light is trapped and emitted in only one direction.

9. The 1960s also brought the development of another very important class of laser, "optical fiber lasers," the subject of the present litigation.

B. <u>Fiber Optics And Light Transmission</u>

1. <u>Refraction of light</u>

10. An "optical fiber" is a long, thin strand of glass (a "fiber") designed to allow light to travel within it along its length. Optical fibers depend on the concept of light guiding. The basic idea of light guiding starts with the concept of "total internal reflection." Light travels at different speeds in different materials. For example, light travels faster through air than it does through water. The ratio of the speed of light in a vacuum to the speed of light in a given

material is called the "index of refraction" for that material. The higher the index of refraction for a material, the slower light travels in that material. Figure 3, below, shows what happens when light travels from air (a material with a low index of refraction) into water (a material with a higher index of refraction), such that the light is incident upon the water surface at an angle A, commonly known as the "incidence angle" or "angle of incidence." As shown in Figure 3, the light changes direction at the air-water boundary, such that the light travels through the water along a second angle, B, commonly known as the "refracted angle," or "angle of refraction." In the 1600s, Willebrord Snell discovered that the sine of the incidence angle of the incident light is related to the sine of the angle of the refracted light in proportion to the relative index of refraction of each medium.

11. For air, the index of refraction is close to one. For water, the index of refraction is around 1.33. For many glasses, the index of refraction is around 1.50. The index of refraction depends on wavelength as well as material properties such as density and temperature, and it can be changed for a given material by doping it with other substances. In Figure 3, below, we see that the light is bent towards the perpendicular line (the dashed line in Figure 3) when the index of refraction is higher in the second medium. Snell's Law allows us to determine precisely how the light will be bent if we know the index of refraction, or it allows us to measure the refracted angle, and then determine the index of refraction, if such a measurement is desired.

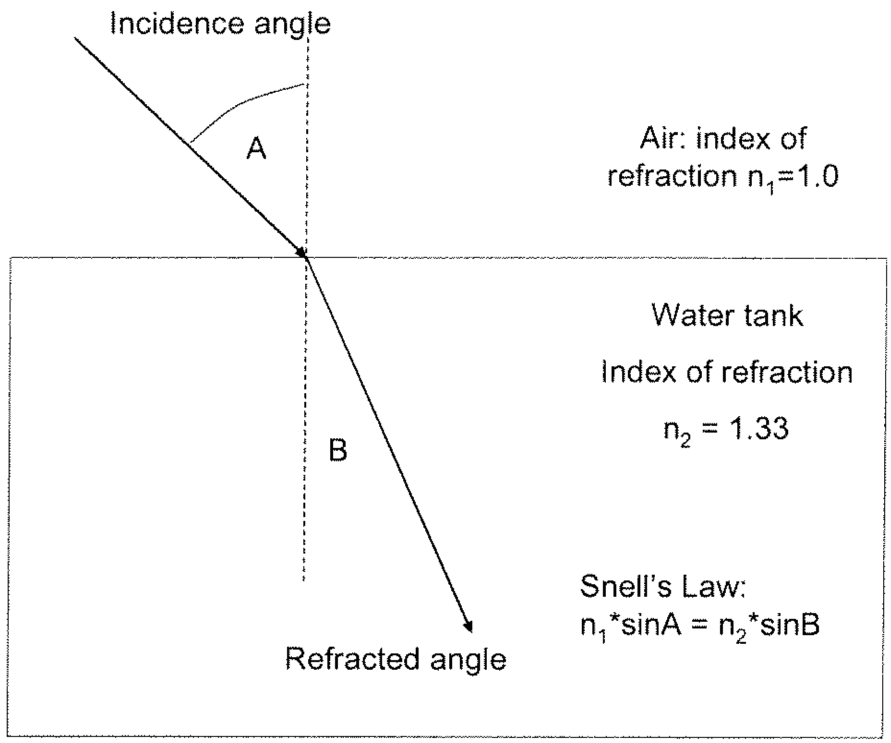

FIGURE 3.

Refraction of light at an air-water interface.

12. Now, we notice an interesting thing when the incidence angle goes to 90 degrees. The refracted light bends at a limit, which is called the "critical angle." Using Snell's Law, we can determine the critical angle. For an air-water interface, the critical angle B_c= arcsin(1/1.33), or about 49 degrees. This is shown in Figure 4, below.

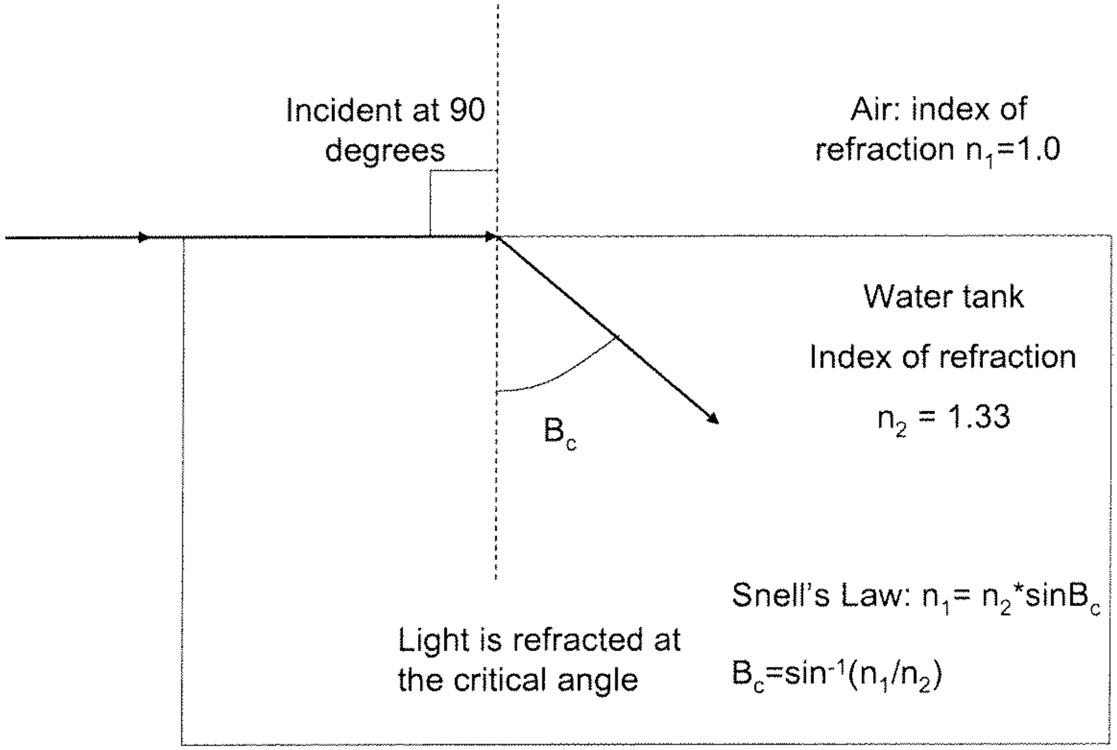

FIGURE 4.

Refraction of light at near normal incidence.

Light is refracted at the critical angle.

13. Now, we may also consider the case where light travels from the water to the air, such as if we used a flashlight underwater. In this case, we would notice that if light is incident on the water-air interface at an angle greater than the critical angle, all of the light is reflected at the water surface, and none of the light travels out of the water and into the air above. This process is called "total internal reflection," and it is perhaps the most important concept in fiber optics.

14. Figure 5, below, demonstrates total internal reflection.

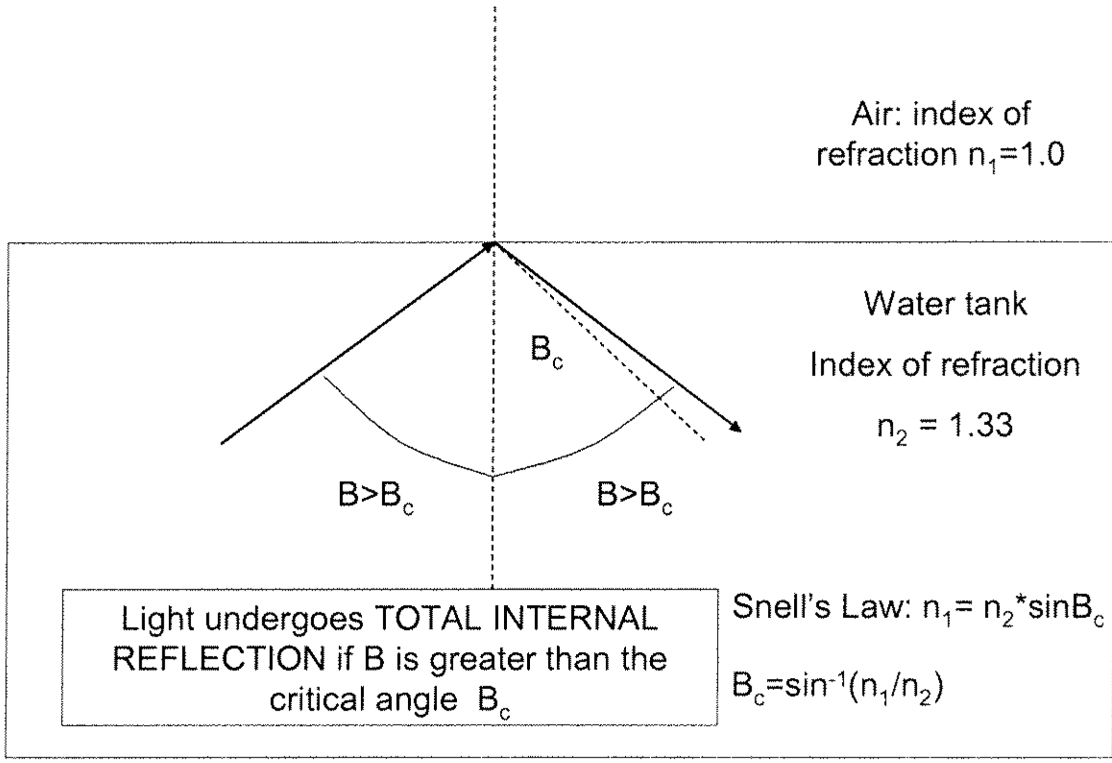

FIGURE 5.

Total internal reflection process when the light is incident at an angle that is larger than the critical angle. The reflection is 100%.

15. In the 1800s, Colladon demonstrated total internal reflection using a water stream with a light source, and just 15 years later, Paris was lit up with colored fountains using this technology. Figure 6, below, shows how the process of total internal reflection is applied to the simplest form of optical fiber, a rod-shaped section of material (e.g., glass) with smooth surfaces and an index of refraction higher than the index of refraction of the surrounding medium. Figure 6 illustrates a glass rod with an index of refraction of 1.50 within air having an index of refraction of 1.00.

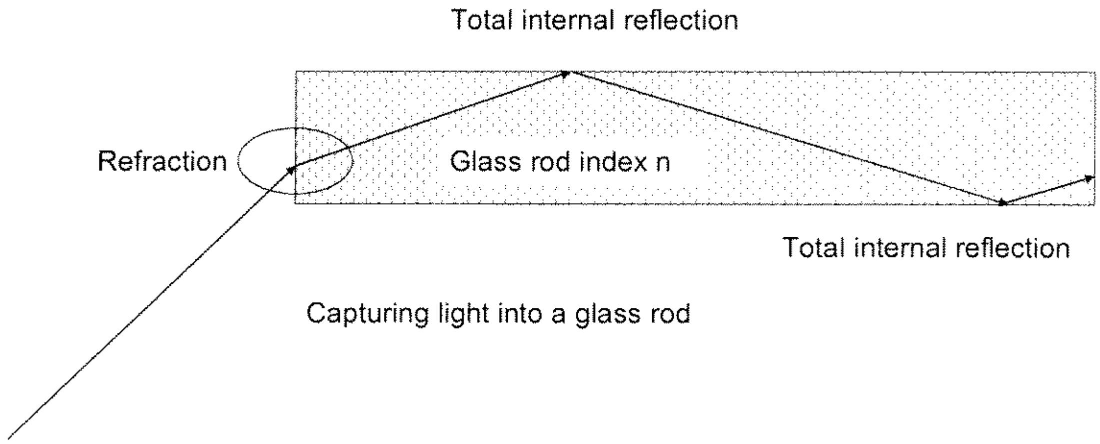

FIGURE 6.

Light is incident on a glass rod. It is refracted at the front end surface, and totally internally reflected at the side surface, because the incident angle is greater than the critical angle in the rod. The light is trapped inside.

16. If we wanted to trap light in a glass rod such as in Figure 6 and transmit it over a distance, the rod in Figure 6 would not work very well. This is because the light trapping is easily spoiled if a material with an index of refraction similar or higher than glass comes into contact with the rod's surface. In the 1960s, Prof. Brian O'Brien, who was the Director of The Institute of Optics at the University of Rochester in Rochester, New York, realized that placing around the rod a second kind of material with a lower index of refraction than the glass in the rod would effectively protect the light inside the center rod from being lost. In this case, it would not matter if an object were placed against the outside layer. The outside layer is called a "cladding" layer, and the inner rod is called the "core." Figure 7 shows how the situation is changed by the addition of a lower index of refraction cladding layer. With light incident at angle *A*, light refracts into the fiber at the fiber end surface, as before, but now there is total internal reflection at the boundary between the higher index of refraction central core and the lower index of refraction cladding layer.

17. Now, the concept of core and cladding layers can be used to make optical fibers. If the structure in Figure 7 is made smaller and longer, it would be possible to transmit light over

a great distance. There is a limit to the angle that can be totally internally reflected, and this consideration leads to the condition that the sine of the maximum acceptance angle *A*, which is also known as the "numerical aperture," or NA of the fiber, is approximated by the following equation where n_1 is the core index of refraction and n_2 is the cladding index of refraction.

$$NA = \sqrt{n_1^2 - n_2^2}$$

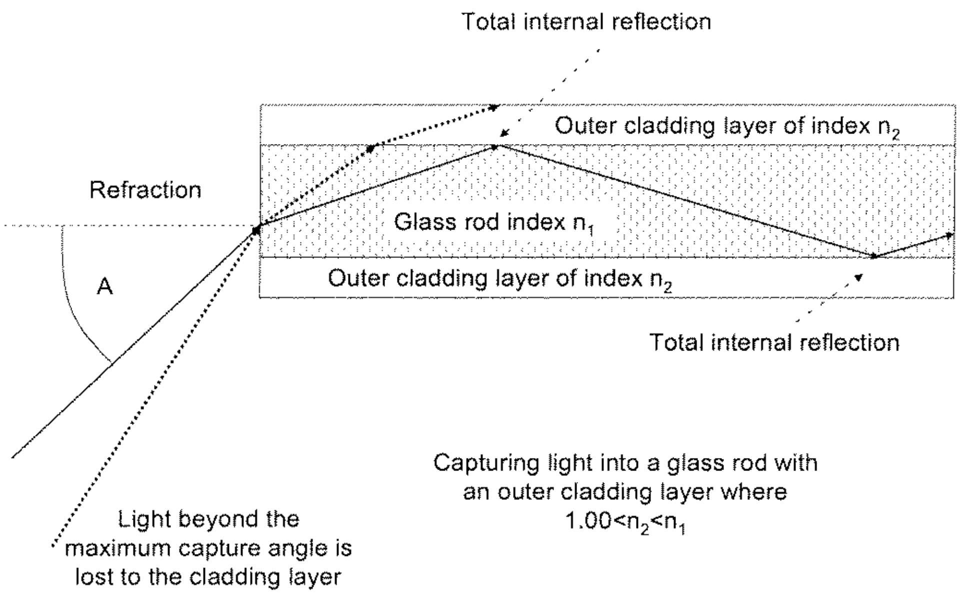

FIGURE 7.

An outer cladding layer is added to the glass rod core, and now the light is confined to the core by total internal reflection that cannot be disrupted by objects placed against the outer cladding layer, when all of the light is propagating in the core.

2. <u>Modes of Optical Fibers</u>

18. Many types of optical fibers have been developed over the years. Early optical fibers were simple light guides, used to transport light from one place to another. An optical fiber

can be as simple as a thin plastic rod, which when bundled into many fibers, can be used for lighting up Christmas trees, for example. Early optical communications systems (in the 1980s) used large-core optical fibers with LED light sources. The large-core optical fibers were easy to connect together, and they worked well with LED light sources. Over time, optical fibers became more sophisticated as new materials became available, as well as new designs and new fabrication techniques. These early large-core optical fibers (also called multi-mode optical fibers for reasons that will soon become apparent) limited the amount of information that could be transmitted over the fibers. They were eventually replaced by much smaller optical fibers that could transmit huge amounts of data. These newer kinds of optical fibers were called "single-mode" optical fibers and created a world-wide revolution in telecommunications, with almost unlimited communications capacity.

19. As will be explained below, there is a difference between single-mode optical fibers and multi-mode optical fibers. Light behaves as a wave, and waves can be trapped within confined spaces only in certain discrete ways, or "modes." In the case of single-mode optical fibers, the light traveling through the fiber is forced to remain in a single "mode." In the case of multi-mode optical fibers, the light traveling through the fiber is not so tightly confined, and it has the ability to travel through the fiber in many different modes.

20. As we discussed previously, the total internal reflection of light in an optical fiber structure similar to the double-clad structure shown in Figure 7 keeps the light confined in the core. This means that the light cannot escape into the cladding. This confinement of light to the core results in light traveling through the fiber in one or more modes, depending upon the wavelength of the light and the index of refraction profile of the fiber.

21. In the case of light, perhaps this idea of "modes" is strange, but in the case of a drum head it may be more familiar. A drum membrane is tied down at the edges so that it cannot move. This simple fact defines certain modes of vibration of the drum membrane.

22. For example, Figure 8, below, shows four different vibrational modes of a drum. Each mode has a "resonant" frequency (a frequency at which the drum membrane vibrates naturally) and a particular vibration pattern. In the case of the drum, we know that different sounds can be made by hitting the membrane in different ways. This will excite different combinations of modes that will in turn create different sounds.

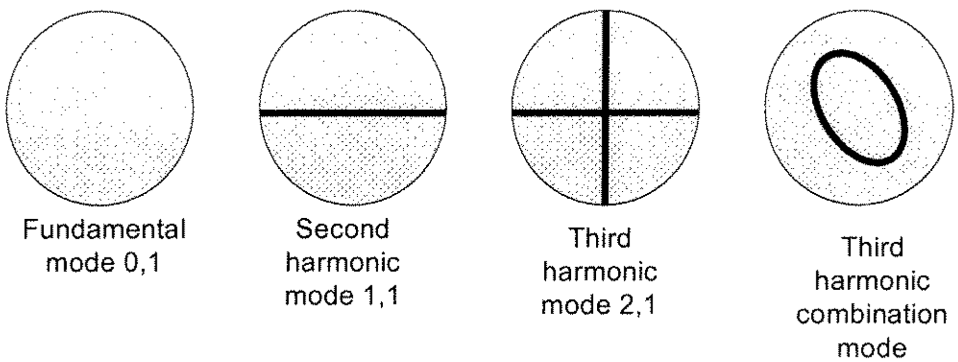

FIGURE 8.

Representation of the different low-order vibrational modes of a drum. The individual vibrational modes can be excited, or groups of modes can be excited with different phases to produce different sounds of the drum.

23. Modes are often referred to in terms of a single "fundamental" (or lowest order) mode and "harmonic" (or higher order) modes. The fundamental mode of the drum is shown in Figure 8 in the left-most drawing. In the fundamental mode, the entire drum membrane vibrates up and down together, and there are no stationary points (i.e. points where the membrane remains motionless) on the drum surface, other than at the edges where the drum surface is confined to its base. Figure 8 also depicts the second harmonic mode of the drum, wherein the entire drum membrane vibrates, but not in unison, as is the case in the fundamental mode. In the case of the second harmonic, half of the drum membrane vibrates upward while the other half vibrates downward. As the upwardly vibrating portion of the drum membrane changes course and begins to move in the downward direction, the other half of the membrane likewise reverses

its course and begins to move in the upward direction. In the case of the second harmonic, there is a stationary line (drawn in Figure 8) depicting points on the drum's membrane that remain motionless during the vibrations. Figure 8 further depicts a third harmonic mode of the drum, wherein the drum membrane vibrates in quadrants, such that adjacent quadrants are out of phase (when one quadrant is moving upward, the adjacent quadrants are moving downwards). In the case of the third harmonic, there are two stationary lines, as shown in Figure 8, depicting the points on the membrane that remain motionless during the third harmonic vibrations. There are several third harmonic modes for a drum, and the right-most drawing depicts a combination mode that combines two different third harmonic modes.

24. The main point here is that the drum membrane can vibrate with different patterns or "modes." Similarly, light waves can only travel within optical fibers in special patterns called modes. And, just as different modes of the drum can be excited by striking the drum in different locations, different optical modes or groups of modes can be excited in an optical fiber. How light travels down an optical fiber will depend on the characteristics of the optical fiber and on the manner in which the light is focused or coupled into the optical fiber.

25. Some kinds of optical fiber can only carry light of a particular wavelength in a single mode. These are called "single-mode" optical fibers. The light coming out of a single-mode optical fiber is sometimes referred to as "diffraction-limited" light. This is because the single-mode optical fiber emits light that consists of no higher order modes. For a single mode-optical fiber, the fundamental mode is the only mode that can propagate, and it presents a Gaussian-like intensity pattern at the exist face of the fiber. The emerging light has the minimum divergence allowed by Physics limits, therefore it can be focused to the smallest possible spot size. This diffraction-limited light, or nearly diffraction-limited light, may be valuable for many applications.

26. Figure 9, below, shows a representation of the modes of an optical fiber that has only two indices of refraction: a higher index in the core and a lower index in a cladding layer with a sharp boundary between them (both illustrated in Figure 9). Such a fiber is sometimes referred to as a "step-index" fiber. The fundamental mode of the fiber (labeled LP01 and l=0, m=1) occupies primarily the central part of the core, and it changes smoothly from a maximum at the center of the core to zero at the boundary between the core and the cladding layer. There are no zeros of intensity anywhere in the core. As shown in Figure 9, the mode labeled LP11 (corresponding to l=1, m=1) has two different maxima located off-center within the core. This mode will have a series of stationary points (locations with zero intensity, i.e. no light) forming a vertical line through the center of the fiber core. Figure 9 also shows a number of additional higher order modes.

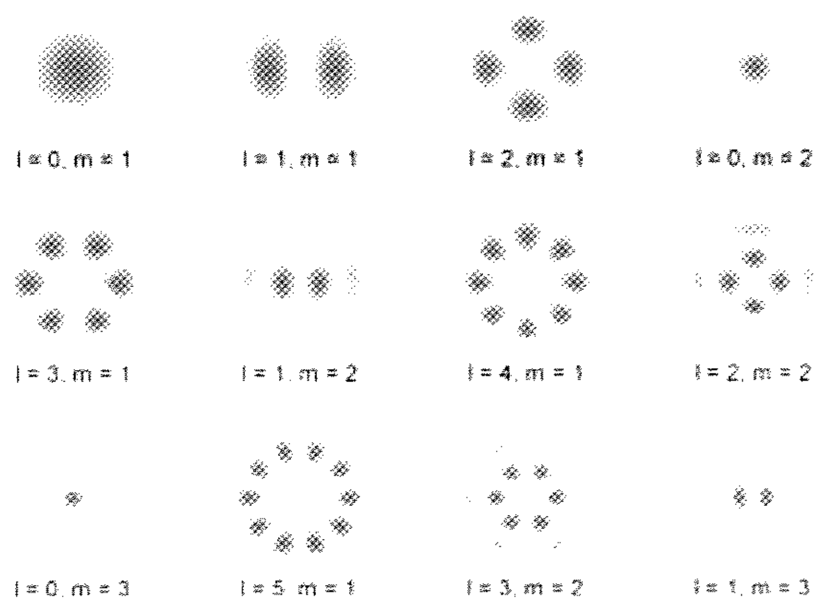

FIGURE 9.

Modes of a step-index optical fiber from R. Paschotta, Field Guide to Lasers, SPIE Press, Bellingham, WA (2008).

27. If a fiber cannot support light propagating in modes higher than the fundamental mode, it is referred to as a single-mode fiber (SMF). Fibers that can support a number of propagating modes are called multi-mode optical fibers, even if they can support propagation with some loss.

28. It is possible to estimate how many modes can be supported in a particular multi-mode optical fiber. In order to estimate the number of modes supported by a fiber, we can first calculate the numerical aperture NA using the equation referenced above. Then, knowing the core diameter d and the wavelength λ, we calculate the parameter V using the following relation, where the NA is defined previously:

$$V = \pi(d/\lambda)NA.$$

29. If V is greater than 2.405, the fiber can support more than one mode (see Patent '630 col. 4, lines 36-38). The number of modes can be estimated for larger V-numbers with the approximate relation:

$$N_{modes} = (V^2)/2$$

3. <u>Doped Fibers</u>

30. It is of interest in the present case to understand how to make fiber lasers, which consist of an optical fiber that amplifies light, and an optical feedback system. Furthermore, once we have established an optical fiber laser emitting light, it is of interest to understand how to make optical fiber amplifiers. These amplifiers raise the light signals to higher power levels. These optical fiber amplifiers operate on the same principal of stimulated emission that we discussed previously. To use an optical fiber as an amplifier, one must create light amplification, or "optical gain," inside the core of the optical fiber. This can be done by incorporating special amplifying atoms into the glass material that forms the core of the fiber. The inclusion of this special material into the fiber is commonly referred to as "doping" the fiber, and the special

material added is commonly referred to as a "dopant." Figure 10 shows an undoped optical fiber, and an identical fiber that has a dopant added to the core material. Possible dopants include Ytterbium, Erbium, Thulium, Samarium, and combinations thereof.

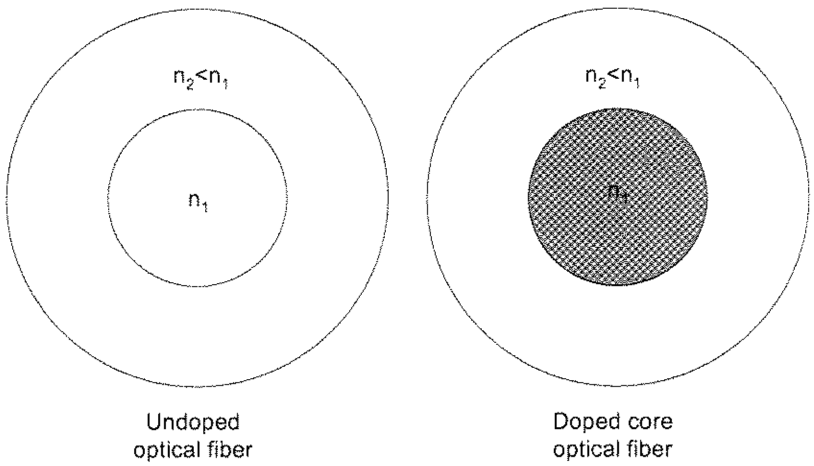

FIGURE 10.

Comparison of an undoped optical fiber with a fiber that has its core region doped with a ions that can be used to provide optical gain.

4. Optical Pumping

31. As discussed above, we can amplify light signals by using the stimulated emission process. If we want to use an optical fiber to amplify, we can start by choosing an optical fiber that has some special amplifying atoms doped into the core region as shown in Figure 10. Next, we need to excite the core atoms into their excited states. This is typically done by introducing light from another laser, such as a laser diode, into the core region to excite the atoms in the core. This is commonly referred to as "optically pumping" the fiber. Figure 11, below, shows two different ways of pumping the fiber.

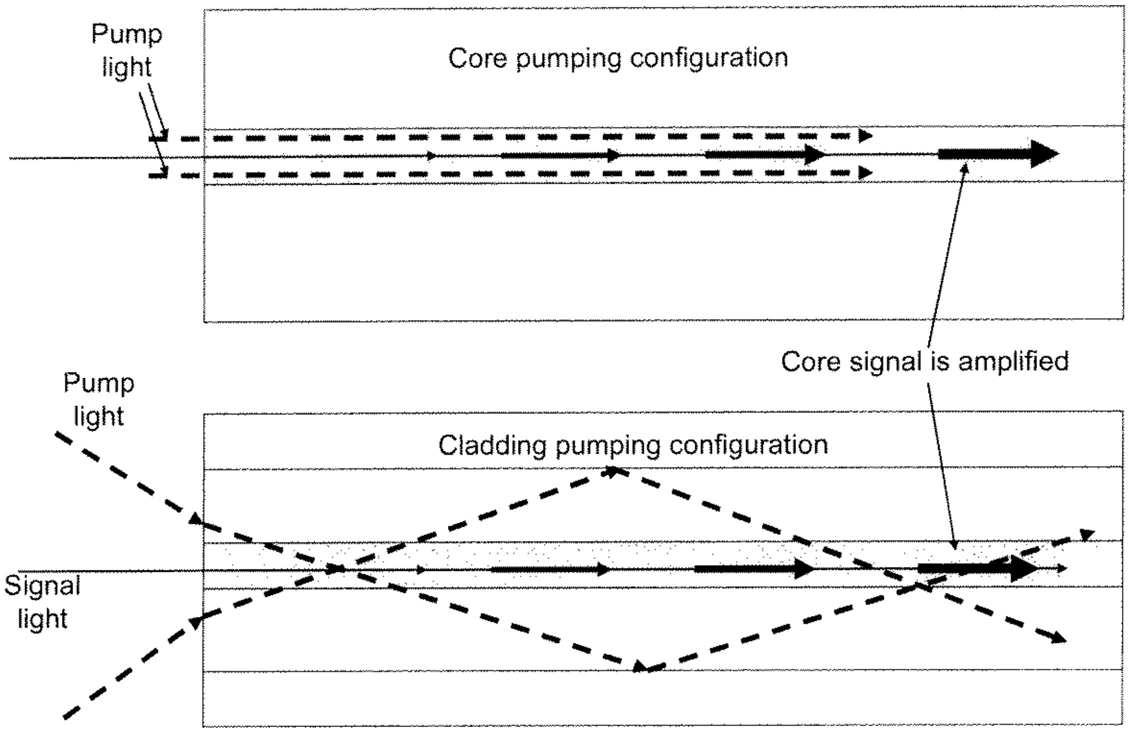

FIGURE 11.

In the core pumping configuration (top)the pump light (dashed lines) is confined to the core, and in the cladding pumping configuration (bottom) the pump light is confined to the cladding and passes through the core many times.

32. The upper illustration in Figure 11 shows a "core-pumping" configuration, wherein pump light is carefully coupled into the core region along with the signal light. This is typically used for lower power lasers or amplifiers with small laser diodes that are easy to couple into the core region. This is also used for shorter optical fibers, since the pump light is strongly absorbed by the core atoms. The core-pumping configuration is normally limited to low powers because it severely limits the type of pump sources that can be used. Very high power pump diodes are available at low cost, however they emit light in highly diverging, low quality beams.

33. The bottom illustration in figure 11 shows a "cladding-pumped" configuration, wherein pump light is introduced into the cladding of the fiber. As shown in Figure 11, a second inner cladding layer is incorporated into the fiber surround the doped core. This inner cladding

layer has an index of refraction that is lower than the core material. Then, a third layer is added around the cladding layer that has another lower index of refraction to trap the cladding light and protect it from the outside. The diameter of the cladding layer is larger than that of the fiber core, so it can be filled with the light that is outputted by cheap high-power pump diodes. Since the pump light is trapped in the inner cladding layer, it will propagate a long distance, crossing through the doped core many times. Each time the pump light passes through the doped core region, it will be partially absorbed and excite some of the ions into their excited states, where they can provide optical gain by interacting with the single-mode light signal that is confined to the fiber core. Since the absorption is weaker in this configuration, it works best for long optical fibers, and these are what are used with very high power fiber lasers.

C. Fiber Lasers, Amplifiers, and Related Components

1. Fiber Laser And Amplifiers

34. It is of interest in the present case to generate a light beam of high quality (close to a parallel beam, with very little spreading) and to be able to amplify the beam, or increase its total power, while maintaining high quality. A fiber laser is a source of light signals. We might think of an electric guitar as a source of a sound signal. By itself, it produces a sound that might be sufficient for a small gathering of people. If, however, we wish to enable 50,000 people at a concert to hear the guitar all at the same time, we can use amplifiers. A very important issue in this example is the quality of the amplifier system. Generally, it is desirable to amplify audio signals while maintaining the signal quality..

35. Figure 12, top picture, shows the configuration for a fiber laser that uses a pair of mirrors for feedback. The mirror on the left side reflects 100% of the core light, and the mirror on the right side allows some of the core light to be transmitted as laser light. Figure 12, bottom picture, shows the configuration for a fiber amplifier, which does not use any mirrors.

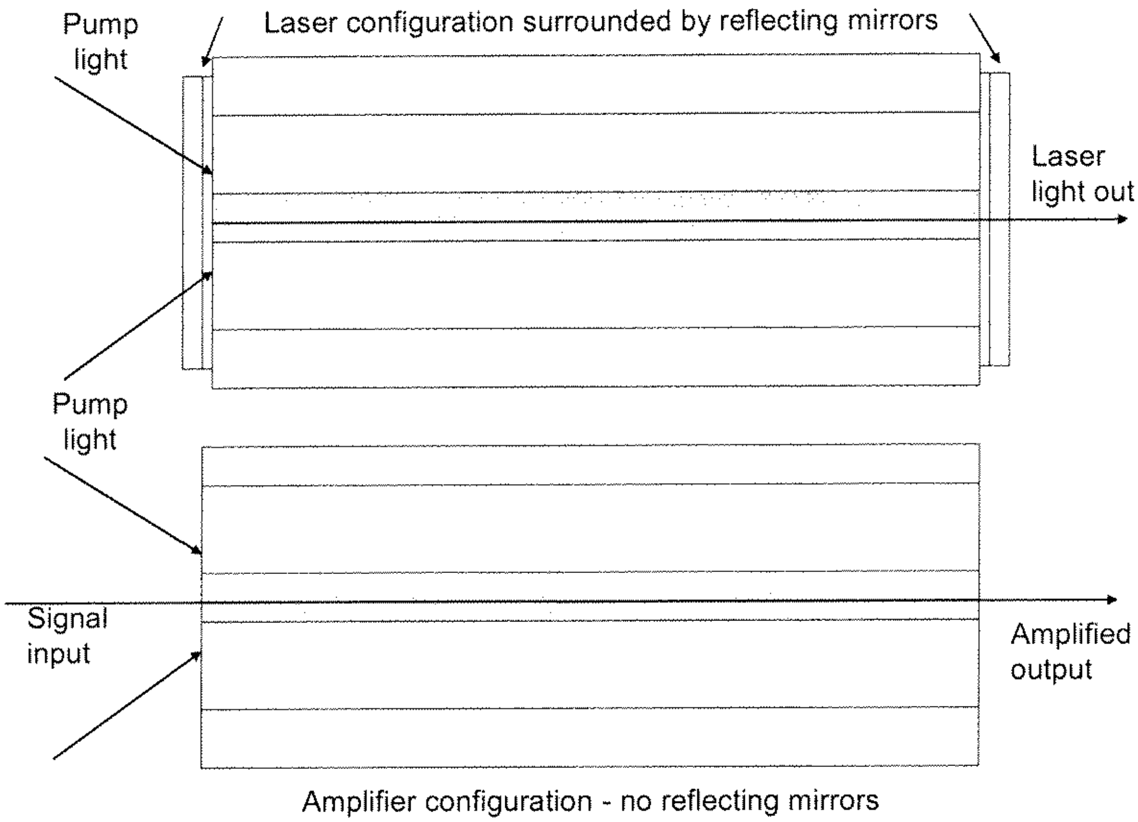

FIGURE 12.

Top: fiber oscillator or laser configuration using mirrors to form a feedback cavity.

Bottom: amplifier configuration has no mirrors.

36. The left-hand mirror in Figure 12 (top illustration) reflects all of the laser light, but transmits all of the pump light. This is a special mirror that is called "dichroic" that reflects only the wavelength of the laser light. The right-hand mirror is a partially reflecting mirror that transmits part of the intra-cavity power. When the pump source is turned on, the lasing action occurs when the total gain is greater than the total loss.

37. In the present case, it is preferred to incorporate the mirrors into the optical fibers by manufacturing the mirrors right into the core of the fibers. They can be created within undoped fibers which are then spliced to the doped fibers, or they can be created directly into the doped fibers, as shown in Figure 13, below.

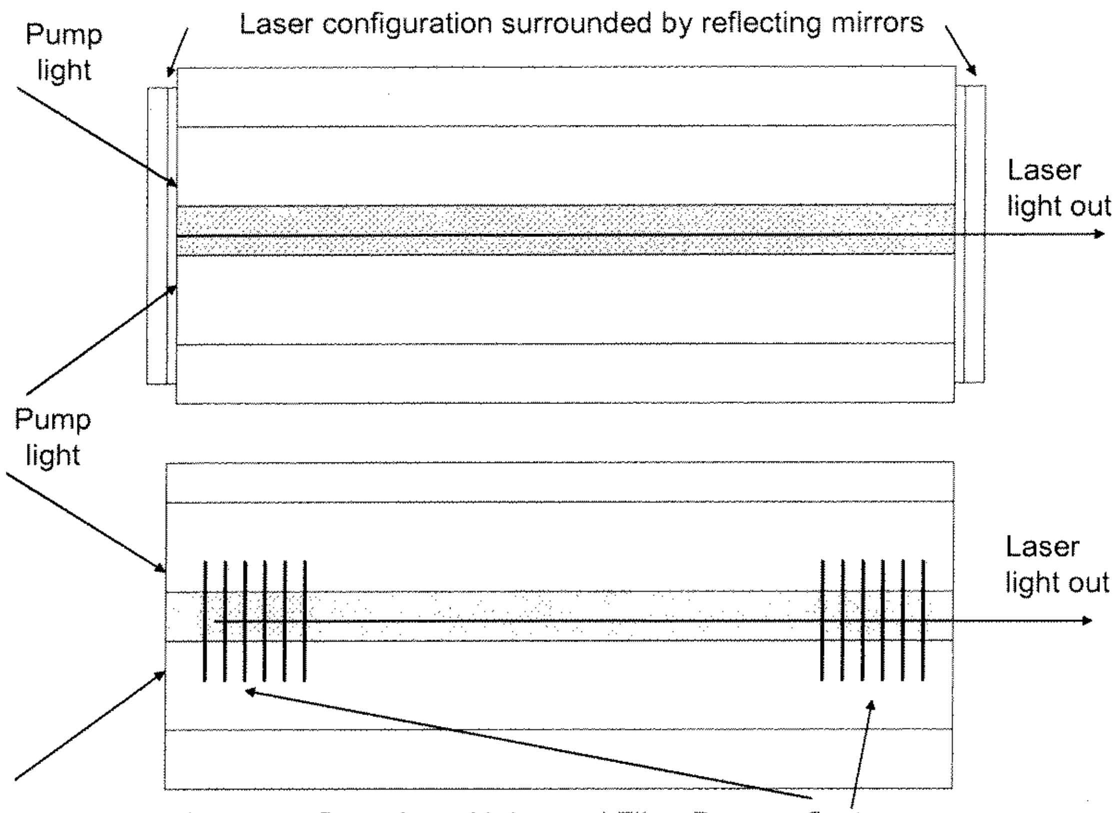

FIGURE 13.

Different schemes to form a laser cavity using external mirrors and using Fiber Bragg Gratings that are formed directly into the gain fiber.

38. Figure 13 compares the use of ordinary mirrors to form the feedback cavity with the case of internally written Fiber Bragg Gratings (FBGs), which are simply a type of mirror that can be formed within a fiber. For the present case, FBGs are preferred since they have no adjustments once they are written into the fibers, and therefore are more reliable.

2. Beam Characterization

39. The quality of optical beams can be characterized in many ways. We can think of this in terms of how small of a focus spot we could achieve if we tried to focus the light. For laser light, it is helpful to be able to focus the light into as small a spot as possible. Many

applications of lasers involve cutting, drilling or welding, and it is desirable to have very small spots in such processes. One commonly used definition to measure the quality of a beam is called the M^2 factor of the beam. The gold standard, or the highest quality beam that can be achieved is called a "diffraction-limited beam," and it is characterized by an M^2 of 1.0. This means that it is possible to focus one of these beams to exactly the spot size allowed by the laws of Physics. If a laser beam has M^2=5, it will focus to a spot size that is 5 times as large as the diffraction-limit.

D. <u>History of Laser Technology Development</u>

40. As discussed above, the development of the laser began with the theoretical discovery of stimulated emission of light by Albert Einstein. The first working laser was later demonstrated by Theodore Maiman in 1960. Maiman's laser used a flash-lamp to pump atoms in a ruby crystal, which emitted a red laser beam. Ever since the first demonstrations of the ruby laser, it was recognized that the laser would revolutionize manufacturing in many ways. In fact, early scientists used ruby lasers to burn holes through razor blades and jokingly suggested the number of razor blades that a laser could cut through as an indication of how much power it was capable of producing in a focused beam. Of course, there are much more sophisticated ways of measuring laser power today.

1. <u>Gas Lasers and Their Applications and Limitations</u>

41. The first gas laser was demonstrated shortly after Maiman's ruby laser. As the name suggests, gas lasers use gases, such as helium, neon, carbon dioxide, oxygen, and nitrogen, for example, to produce stimulated emission of light. These gases are typically contained in a glass tube. They use large power supplies to create a beam of electrons within the tube that excite the gas atoms above their ground state energy levels. The large-frame gas lasers that were developed, such as the carbon dioxide laser, led the way to a revolution in laser machining and manufacturing. And yet, even with the successes of early lasers, there were still many reasons

why it was felt that there was a need for better solutions. For example, gas lasers were problematic because of their large power supplies, fragile glass tubes, and low power efficiency.

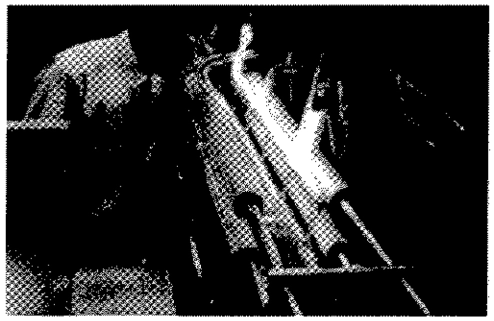

FIGURE 14.
An early carbon dioxide laser (www.Bell-Labs.com).

2. Fiber Lasers And Their Applications And Limitations

42. As the number of applications for lasers was expanding, there was also an increasing need for more compact and rugged systems that could be used, for example, on airborne platforms and other high-vibration environments in which neither gas nor solid state lasers could be used, and in cases where available electrical power and/or space was limited.

43. Fiber lasers held the promise to meet the need within the industry for lasers with increased ruggedness, higher efficiency, lower operating costs, and increased compactness to serve applications where gas and solid state lasers fell short. Yet, there were many technical problems to solve along the way.

44. In the early 1960s, fiber lasers offered power levels only on the order of thousandths of a Watt. Fiber laser power levels rose over time, and by 1990 fiber lasers had achieved Watt-level output powers. Fiber lasers at the time still lagged far below the power levels of carbon dioxide and solid state lasers. Solid state lasers such as Nd:YAG, which stands for Neodymium-doped Yttrium Aluminum Garnet, require large power supplies, water cooling and flashlamps that require frequency maintenance. While the fiber laser enjoyed natural

advantages related to ruggedness, compactness, and efficiency, fiber lasers could not compete with the higher power levels of gas and solid state lasers so that the natural benefits of fiber lasers could be extended to high-power applications.

45. Figure 15, below, shows a chart that depicts the steady progression in power achieved by fiber lasers. The chart is taken from a presentation given by IPG Chief Executive Officer, Dr. V. Gapontsev.

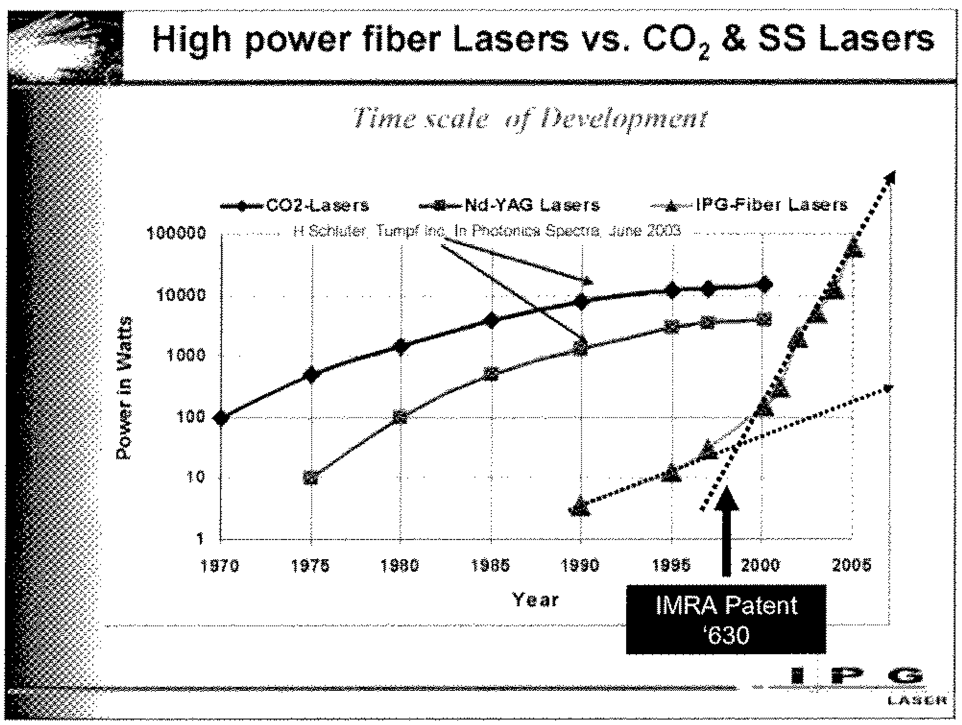

FIGURE 15.

Chart from a presentation by Dr. V. Gapontsev. (IPGI 021536). Dotted lines have been added to show the change in rate of development of high-power fiber lasers that coincides with the timing of the invention described in the '630 patent.

46. The chart shows the development of high-power fiber lasers compared to that of carbon dioxide and Nd:YAG lasers during the past several decades. The respective slopes of the lines in the chart represent the rate of increase of available output power for each type of laser.

The chart reveals that the available output power of carbon dioxide and Nd:YAG lasers increased substantially throughout the 1970s and 1980s but further growth slowed in the 1990s. The chart also illustrates the steady, but relatively slow, increases in output power of fiber lasers that occurred up until the mid-1990s.

47. In the mid-to-late 1990s, the rate of progress in fiber lasers increased dramatically, as illustrated by the large increase in the slope of the line for fiber lasers. The change in the rate of progress is shown by the dotted black lines, which I have added to the chart. The chart shows well the dramatic increase in the rate of progress in the development of high-powered fiber lasers in the late 1990s.

48. The relatively recent improvements in the power levels of fibers lasers have filled a need for rugged and efficient lasers that are also capable of providing high-power, high-quality laser beams. Fiber lasers are now used in a broad range of industrial applications, such as welding, scribing, marking, cutting, annealing, and drilling.

49. The January 2, 2008 issue of *Nature Photonics* included several articles on fiber laser systems. These articles described the work being done at several laser companies, including IMRA, IPG, SPI, and Nufern. The issue opened by highlighting the commercial importance and rapid growth of fiber laser companies:

> Market-analyst company Strategies Unlimited believes that the fibre laser 'represents the most important new technology in the laser industry in a decade,' and it's easy to understand why.
>
> The fibre laser is unlike any other laser on the market. Its unique geometry means it is extremely versatile, giving it applications ranging from ophthalmology to welding cars. In this month's Technology Focus, industry experts look at using fibre lasers for marking . . . , industrial applications . . . , and metrology . . . .
>
> Although these articles show that the fibre laser is already being used in commercial applications, there is still much to learn about his fascinating technology and new applications are emerging all the time. Researchers are constantly pushing the parameters to get more out of the fibre laser. Pulses are becoming shorter, pulse energies higher and power scaling is reading unprecedented levels. . . .

And because of these interesting advances, business is booming and fibre-laser companies are among the fastest growing firms in the laser market.

50. Additional information on the background technology is found in the "Background of the Invention" section of the patent.

DR. WAYNE H. KNOX

Dated: 12/23/2009